

Antennas

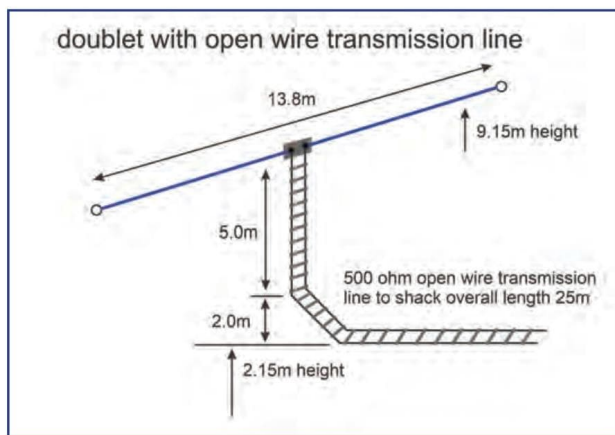


FIGURE 1: A doublet antenna fed with open-wire transmission line.

(Kevin and Steve, heretofore joint authors of 'Antennas', have decided to alternate between joint authorship and single authorship by Kevin. Here is Kevin's first offering.)

VSWR and matching

The general consensus in the mid 1970s, when I got my licence, was that a good impedance match between the antenna, the feed line, and the transmitter was desirable. A low VSWR on the coaxial feed line to the shack was an indicator of a matched antenna and an efficient transfer of power. With most transmitters having valves in the final stages and pi-networks for matching to the transmission line, an acceptable VSWR figure such as 2:1 could easily be tolerated, so the VSWR on the transmission line was not really treated with the same great concern as it is now.

Back in the 1970s, many stations were still using a doublet-style antenna with balanced open-wire line feeders. With good construction, this method of feeding the antenna was very efficient. A high VSWR on the line results in very little VSWR loss as compared to 50Ω or 75Ω coaxial cable. The important thing is being able to match the high impedance to the output of the transmitter using an antenna tuning unit (ATU). With large high-Q coils and high-quality variable capacitors, the loss incurred can be quite low.

Later, the increased availability of 50Ω and cheap 75Ω TV coaxial cable, along with the significant practical installation advantages that these coaxial cables offered over balanced open-wire lines, saw the latter lose popularity. Virtually all equipment specified 50Ω as the impedance, and commercially-made antennas also used 50Ω as a standard impedance. The VSWR of a coaxial cable feed line became of more importance than ever before as a parameter of station and antenna performance.

The importance of VSWR increased with the introduction of transceivers having solid-state semiconductor finals, which could not tolerate

high VSWR and required matching with an external ATU. This handled the mismatch presented by the coaxial cable, and appeared as a 50Ω impedance to the delicate solid-state finals. Transceivers later included an automatic ATU; this was a nice feature, but the reduced size of the critical components in a typical internal ATU contributed more loss than a well-designed larger external ATU.

The Icom IC-7610 internal ATU has a published insertion-loss figure of up to 0.7dB, and my Expert 2KFA amplifier, a very well-constructed piece of equipment, states up to 0.8dB ATU loss. By necessity, these integrated ATUs have to be fairly small and use compact toroidal coils and small high-quality capacitors. The popular Palstar AT2K tuner indicates up to 0.5dB loss at 30MHz. These figures are dependent on the level of VSWR to be matched and, of course, the frequency of operation.

Let's be clear about one thing: being able to match the impedance with an ATU at the radio end of the transmission line does not 'tune' the antenna. The antenna characteristics, such as gain and pattern, are not affected by the type of transmission line at the feed-point. The feed-point impedance of an antenna varies with the height above ground and with the ground conductivity. Both the height and ground characteristics affect the antenna pattern, gain, and the elevation of the main lobe. These antenna parameters can be modelled quite accurately using programs such as EZNEC.

Coaxial cable line loss and VSWR loss

The extra loss incurred from a mismatch when using good-quality coaxial cable on the HF bands may not be as significant as you might think. Using a 30m length of LMR400 coaxial feeder as a guide, and 14MHz as the frequency, the inherent line loss of the feeder is 0.447dB and, with a VSWR of 2:1, the extra loss because of the VSWR is an additional 0.1dB, making the total loss 0.546dB. If the VSWR increases to 3:1, the line loss is still 0.447dB but the VSWR loss increases to 0.261dB, making a total loss figure of 0.708dB. It's worth noting that most of the loss in this example comes from the cable line loss, not the increased VSWR. Most internal transceiver or amplifier ATUs should be able to handle this VSWR mismatch, and a dedicated well-constructed external ATU would have no problem at all.

Open-wire transmission line has much less loss than conventional coaxial cable. It can handle a high VSWR with very-low additional loss, has a velocity factor of about 0.95, and can tolerate high voltages. Care has to be taken to keep the line balanced and away from metallic objects, the ground, and other

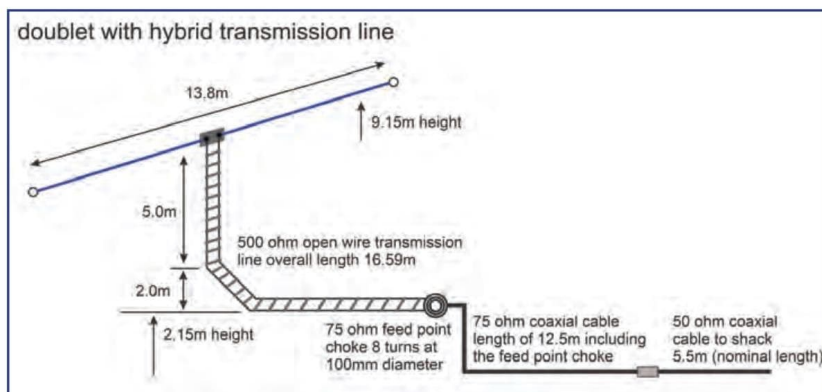


FIGURE 2: A doublet antenna fed with a hybrid transmission line.

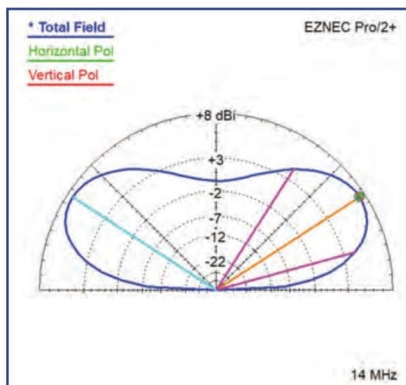


FIGURE 3: 14MHz elevation pattern of the doublet antenna.

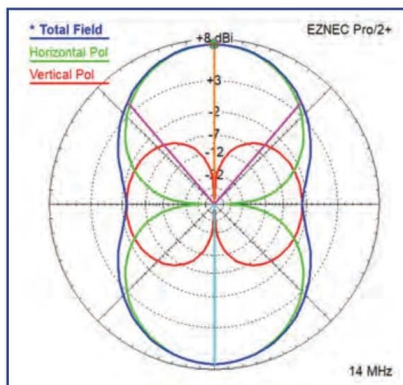


FIGURE 4: 14MHz azimuth pattern of the doublet antenna.

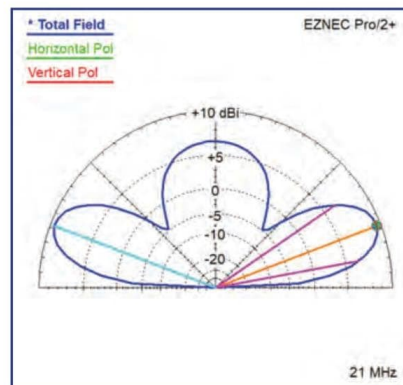


FIGURE 5: 21MHz elevation pattern of the doublet antenna.

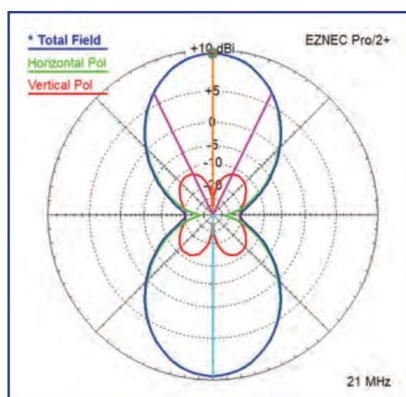


FIGURE 6: 21MHz azimuth pattern of the doublet antenna.

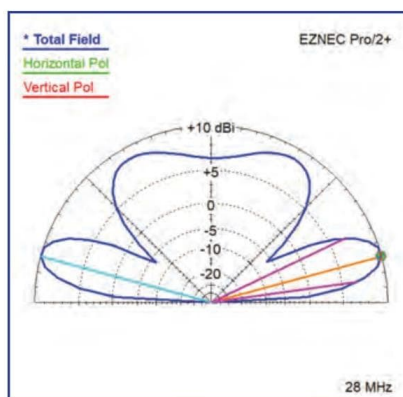


FIGURE 7: 28MHz elevation pattern of the doublet antenna.

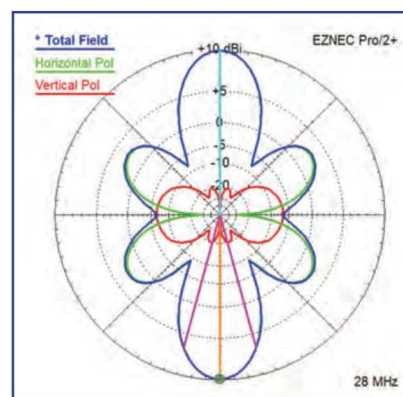


FIGURE 8: 28MHz azimuth pattern of the doublet antenna.

buildings. With a correctly-balanced transmission line, even though the VSWR may be high, there is little radiation from the line because the voltage and current phases in each conductor cancel one another. However, getting the open-wire line into the shack is difficult, and requires feed-through insulators. There may also be high RF voltages. Of course, at the point of entry, you still need to be able to match the high or low, usually complex impedance to the 50Ω required by your radio.

ATUs and the balun problem

An external ATU with a balanced output will be needed to provide a wide range of impedance transformation to 50Ω. Ideally, an ATU with a dedicated balanced open-wire line connection is the best option. The build quality and power rating are important. A number of commercial ATUs provide a balanced connection for 50Ω coaxial cable, achieved using a 4:1 toroidal balun. This is really just a compromise solution to save money and space; it can be viable, but it is limited in scope. Let's consider that you want to match the open-wire line feeding a doublet antenna across seven or eight bands. On any given frequency, the doublet antenna has a certain

feed-point impedance, and unless it happens to be exactly resonant it will include reactance as well as resistance. The open-wire transmission line connects at this point, and we have a balanced antenna fed with a balanced transmission line. This acts a transformer in a repetitive fashion (depending on its length) and usually presents a different impedance at the other end.

For example, at a given frequency we can measure the same impedance at each half line-wavelength from the doublet feed-point. Similarly, each multiple of a quarter wavelength will show a reversal of impedance magnitude from low to high and vice versa. An ATU with a 4:1 balun at the output may not help, especially if the impedance is quite low; the resistive part could be perhaps around 20Ω, and the ATU itself would then be dealing with something like 5Ω. The balun may also not cope well with high levels of reactance. A well-constructed 1:1 balun for this type of ATU would perhaps be a better choice. Choosing the best length for the transmission line to keep the ATU happy on every band is not easy. However, with EZNEC a 'sweep' of the VSWR across the frequencies of interest will show resistance and either inductive or capacitive reactance. From that data, it's possible to deduce the best

overall impedance match that will be within the capabilities of the ATU.

We now turn our attention to the most important characteristics of the antenna: the pattern and the gain. If DX is the goal, then low-angle gain is desirable. For short- or medium-distance QSOs, a higher angle might be better. Just by adjusting the height above ground you can change the pattern, the gain, the take-off angle of the main lobe, and the feed-point impedance. Ground reflection on HF will vary according to each location.

Practical example

Figure 1 shows a compact wire antenna, a version of which I have used during portable operations. This can be effective on HF bands and even on 6m.

Kevin Smith, VK6LW/VK6T
ex G4EHF
 instagram @vk6lw,
 youtube @vk6lw,
 email vk6lw.kev@gmail.com

The overall length is 13.8m, which corresponds to two half waves in phase on the 15m band. At a height of 9.15m, this flat-top doublet antenna displays a bi-directional pattern with a modest gain over a dipole. The impedance on 15m at the centre of this doublet will be very high, around 4000Ω, entirely resistive at resonance. If only single-band operation is required, it can be fed with an electrical quarter-wave open-wire transmission line providing a good match to 50Ω. However, feeding the antenna with a longer length of open wire transmission line provides an opportunity to match the antenna on some other bands too. With some help from EZNEC, I found a 25m length of 500Ω open-wire transmission line gives a range of manageable impedances, which when connected to an ATU should provide a match on all bands from 30m to 6m. Even on 40m, which shows the highest VSWR, it should still be possible to achieve a match using a well-constructed ATU having the capability to match a large impedance range. **Table 1** provides more information regarding the VSWR and loss figures for selected frequencies.

I've chosen 500Ω open-wire line as it's lighter, has less wind loading, and is mechanically more stable than the 600Ω version. Spacing for a 500Ω transmission line is 65mm using 2mm diameter wire. However, 450Ω window ladder line could be used, as could the wider-spaced 600Ω. The difference between using these transmissions lines will be negligible. In the March 2025 Antennas column, there is some useful information about open-wire line construction. Aluminium electric fence wire of 2mm diameter is a good choice. This light-weight wire greatly reduces the sag that would otherwise be incurred by using copper wire.

On 40 and 30m, the radiation pattern is largely omnidirectional, with medium to high take-off angles. This is consistent with an antenna height of 9.15m. On 20m, the main lobe of the pattern lowers and the gain improves. For the higher HF bands, the gain increases with frequency and the elevation angle reduces still further, with enhanced performance for DX. There is also a significant high-angle component caused by ground reflection at this height, which will help with shorter-range QSOs.

A hybrid transmission line system (**Figure 2**) may also be of interest. At around 16.59m the open-wire transmission line is joined to a 75Ω RG11 coaxial cable having a velocity factor of 0.84, via an air-core balun choke. This 12.5m length of RG11 provides an impedance transformation improving the match on 20m and

10m, while the match on 15m is not affected. The important characteristics of the doublet antenna on these three bands are retained as there is no effect on pattern or gain. The downside is that only three bands can be matched. The benefit is that on 15 and 10m the match presented in the shack is very good, and on 20m it can be handled easily by the internal ATU of most transceivers.

In the interests of calculating the overall transmission line loss for the hybrid system, I've included 5.5m of 50Ω LMR400 cable. This length is not critical depending on the distance from the antenna to the shack. Adding the data together from **Table 2** and **Table 3**, we arrive at the following loss figures for the hybrid system: 0.467dB at 14.2MHz, 0.540dB at 21.2MHz, and 0.607dB at 28.0MHz.

As expected from **Table 1**, the 25m open-wire transmission line direct to the shack ATU has the lowest loss figure. The interesting aspect of this, when comparing the total loss data, is that we find that the major reason for the higher-loss figure for the hybrid system comes from the line loss of the coaxial cable, not the additional VSWR loss. I have not tried to take into account any extra loss that might be incurred by the ATU.

Table 4 shows the gain figures modelled for each band, and the corresponding elevation angle.

If only a single support is available, this antenna could be configured as an inverted vee with a suggested minimum apex angle of 120°. The feed-point impedance will be different from the flat-top arrangement shown, but the patterns and gains will be similar, and overall losses will still be low on all the bands. With limited space, the open-wire transmission line direct to the ATU may be too long. This can be reduced without affecting antenna performance to suit the space

available, provided the ATU can still match the various impedances presented.

The hybrid transmission line version (**Figure 2**) is suitable for 20, 15 and 10m. The open-wire transmission line can also be made with 600Ω open-wire line or 450Ω window ladder line. The latter is commercially available and, as the velocity factor is slightly lower at around 0.91, the line length reduces to about 15.90m.

Some other configurations to consider

This type of antenna can easily be scaled to other bands. For 15m, if the 500Ω open-wire transmission line is reduced to 3.25m corresponding to a quarter wavelength, the high impedance of the two half waves in phase at the doublet centre are transformed to a 50Ω feed-point. There is also a low-impedance match on the 6m band as a bonus. Similarly, if the open-wire transmission line has a length of 7.74m, a good match is achieved on both 20 and 12m. In this case 50Ω coaxial cable can be used, but the modelling shows a better match with 75Ω RG11 coaxial cable. A slightly-larger antenna, having two half waves in phase for 20m at a height of about 12m, would be very effective and the performance on 40m would also be greatly improved. It would still be possible to use the antenna on all the higher HF bands with the open-wire transmission line fed directly to the ATU in the shack.

In conclusion, it's important to remember that the VSWR on the feeder is an indicator of the transmission-line efficiency. It's not an indicator of the performance of the antenna itself.

Table 1: Impedance presented to the ATU, VSWR and losses of a 25m length of 500Ω open-wire transmission line connected to the antenna shown in **Figure 1.**

frequency MHz	impedance/ohms R X	VSWR	line loss dB	VSWR loss dB	total loss dB
7.1	17 +j21	28.1:1	0.042	0.509	0.551
10.1	144 -j502	7.12:1	0.05	0.129	0.179
14.2	203 -j453	4.68:1	0.06	0.085	0.145
18.1	572 -j1177	6.71:1	0.068	0.159	0.227
21.2	128 +j497	7.90:1	0.013	0.212	0.285
24.9	62 +j22	8.02:1	0.08	0.234	0.314
28.2	160 -j596	7.75:1	0.085	0.323	0.408
50.5	293 -j739	5.84:1	0.115	0.219	0.334

Table 2: Losses in a 16.59m length of 500Ω open-wire transmission line connected to the antenna shown in **Figure 1.**

frequency MHz	line loss dB	VSWR loss dB	total loss dB
14.2	0.04	0.058	0.097
21.2	0.049	0.152	0.201
28.0	0.056	0.169	0.225

Table 3: VSWR and losses in an 18m length of coaxial cable, with a combination of a 75Ω matching section and 50Ω coaxial cable to the shack, connected as shown in **Figure 2.**

frequency MHz	VSWR	line loss dB	VSWR loss dB	total loss dB
14.2	2.4	0.268	0.102	0.37
21.2	1.3	0.329	0.011	0.339
28.0	1.1	0.381	0.002	0.382

Table 4: The gain of the main lobe of the doublet antenna per band.

band	gain/dBi	elevation angle/deg
40m	5.32	87
30m	6.16	48
20m	7.24	33
17m	9.07	24
15m	9.58	21
12m	9.79	18
10m	9.94	15
6m	9.64	9